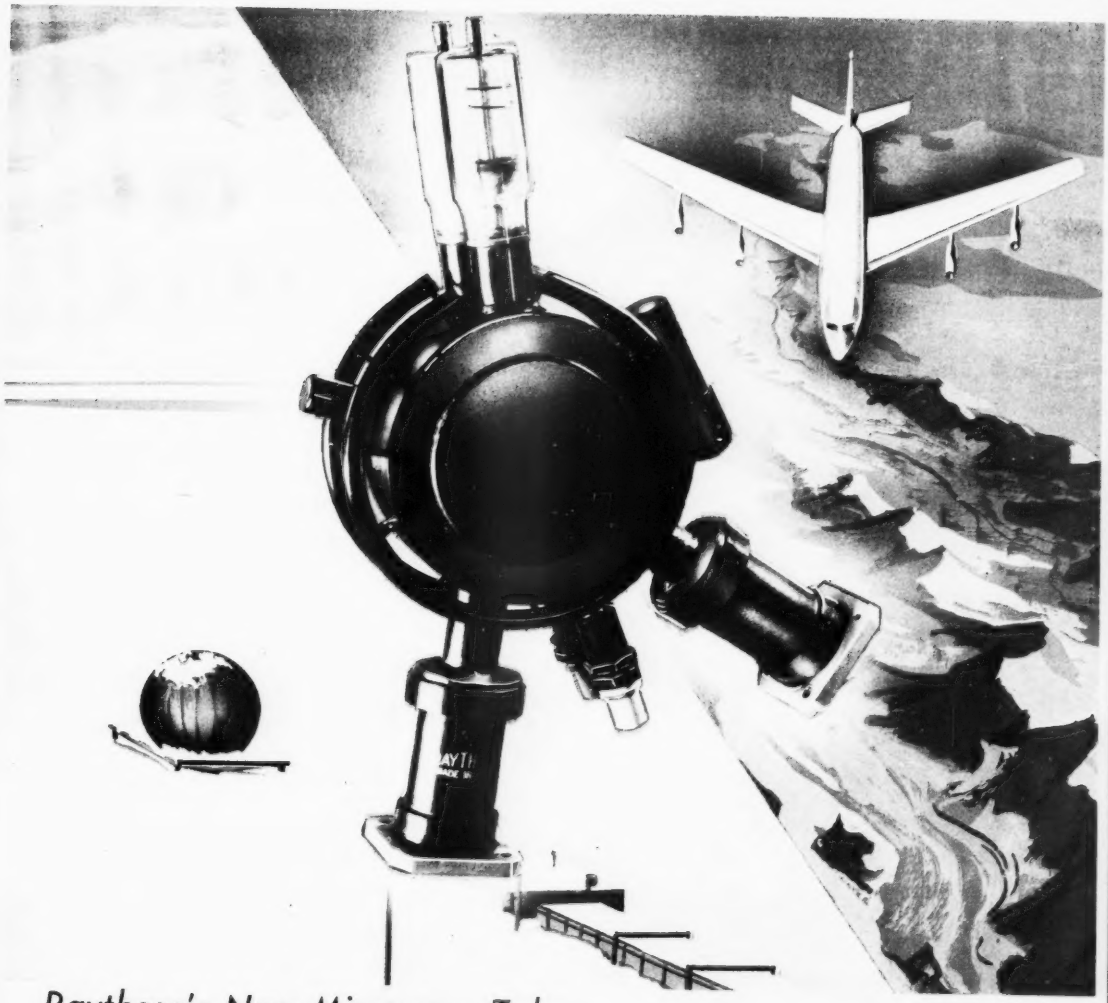
RAYTHEON

ELECTRONIC PROGRESS

JULY
AUGUST 1957



Raytheon's New Microwave Tube

In this issue: THE AMPLITRON

ELECTRONIC PROGRESS

Volume II July-August 1957 Number 1

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Waltham 54, Mass.

THE COVER

Raytheon's new type of microwave tube, the platinotron, is superimposed upon a background designed to show some of its possible applications to both military and commercial electronics. The platinotron, used as a broadband amplifier, provides increased range and improved overall coverage for existing search radar systems.

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Inventions

Congratulations to the following persons for their valuable contributions to Raytheon's portfolio of inventions:

Name	*Field of Invention*
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John Beebe	Depth Sounder
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Louis Goodman	Paper Drive Mechanism
Duane Haagensen	Electronic Oven Electronic Oven System Diathermy Applicator
William Hall	Commercial Marine Radar Display
Stephen Hannon	Leakage Reactance Control
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John Williams	Penetration of Alloys

Contents

The Platinotron and Its Broadband Amplifier Application, "Amplitron" ..... *W. C. Brown* 1

Metallography Applied to Semiconductors ..... *K. Berberian* 6

Reliability — A Must ..... *W. E. Lowery* 8

Operating-Time Indicators ..... *W. T. Eriksen* 10

Product Engineering ..... *A. D. White* 12

The Platinotron and Its Broadband Amplifier Application, "Amplitron"*

W. C. BROWN
Microwave and Power Tube Operations

MILITARY and commercial electronics are making increasingly critical demands on microwave tubes. Particularly in the field of transmitters, there has been a need for an amplifier tube which combines the property of broad bandwidth with high efficiency, high rf power output, compact envelope size, modest operating potential, and light weight. Of only slightly less importance has been the need for a much more highly frequency-stabilized oscillator for a high power transmitter in MTI applications.

Considering the marked differences in the nature of a broadband high-power amplifier and a highly stabilized self-excited oscillator, it is somewhat surprising to find that a newly developed device satisfies both of these requirements. It is perhaps even more surprising to find that this new device, the "Platinotron",** is rooted deeply in the magnetron, a tube of proven capabilities as the heart of radar systems.

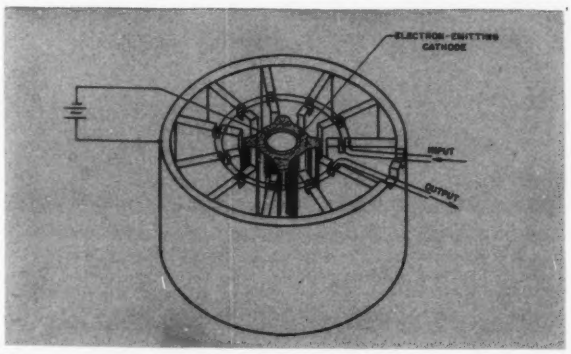
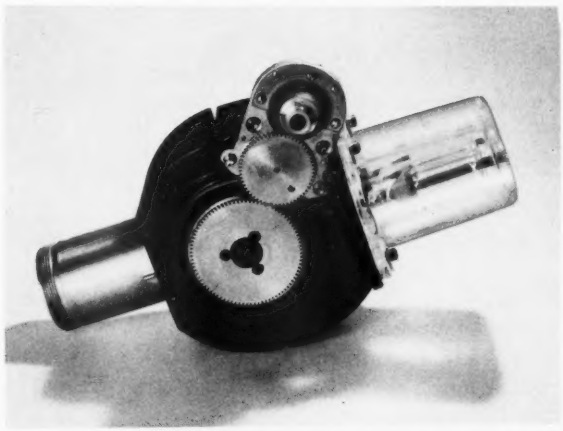


Figure 1a. Photograph and schematic diagram of a platinotron.



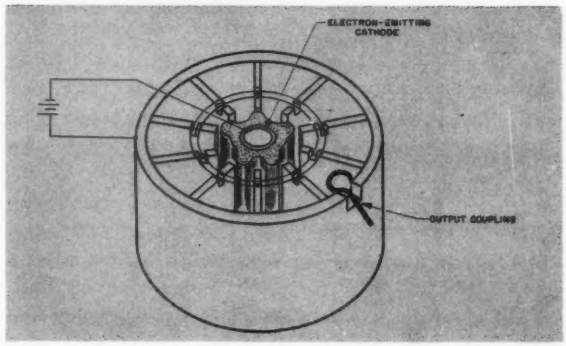


Figure 1b. Photograph and schematic diagram of a magnetron.

The platinotron, as can be seen from Figure 1, resembles mechanically and in appearance a high-powered magnetron except that there are two rf connections, rather than one. As with the magnetron, a circular network is utilized for the rf circuit and the electron beam is originated from a continuously-coated cathode coaxial to this network. And, as with the magnetron, the electron beam is reentrant — that is, the electron bunches circulate continuously. The

* Raytheon Trademark.

** The Platinotron device is proprietary to the Raytheon Manufacturing Company. The early and continued support of the Evans Signal Laboratory in developing this device for military use is acknowledged.

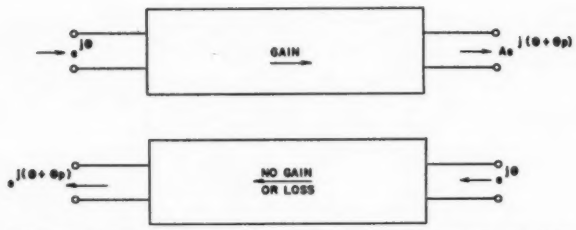


Figure 2. The circuit element characterization of the platinotron.

rf circuit, however, differs from that of the magnetron in that it is non-reentrant and is matched at both ends of the frequency region of interest. Another difference results from the fact that the magnetron is normally used in a mode of operation which places the frequency at one end of the pass-band of the network whereas the platinotron operates in a region of the pass-band well removed from cutoff. These differences from the magnetron are sufficient to make the new device capable of broadband amplifier behavior. That is, it is possible to feed energy in at one of the platinotron terminals and to obtain from ten to sixty times as much power from the other terminal at the same frequency. This can be done over a 10% frequency range without any mechanical or electrical adjustment of the platinotron.

As previously suggested, the platinotron has at least two practical uses. As a saturated amplifier, useful for pulsed radar or fm communications, it is called an "Amplitron." The platinotron may also be used as a self-excited oscillator and if used in this fashion, together with suitable frequency-stabilizing circuits in the feedback path, it is called a "Stabilotron". * A third possible application is its use as a regenerative amplifier in which mismatches in both input and output are so placed as to give a reflection which reinforces the driving signal. In this paper we will confine our attention primarily to the performance of this device as an amplifier.

In an amplifier, we are concerned with a circuit element with two sets of terminals, one set for the input signal, and one set for the output signal. Figure 2 represents the platinotron device in this way. Considered in this fashion, the device is a non-reciprocal, two terminal-pair network with amplification in one direction and passive attenuation, usually very small, in the other direction. The phase shift through the network is nearly the same in either direction. The circuit designer will recognize this circuit element as being new and unique. With it he can do such interesting things as duplexing (switching between transmitter and receiver) at a low power level on the input side of the final amplifier without increasing the noise level of the system more than the small fraction of a db represented by the insertion loss of the Amplitron. It also makes possible a simple way to construct from the platinotron a highly frequency-stabilized oscillator in which the feedback path for the energy can be within the tube itself rather than through an external path.

As an amplifier, the platinotron device behaves as a saturated amplifier rather than as a linear one. By this it is meant that the magnitude of the rf output is relatively independent ** of the magnitude of the rf input, but rather is dependent upon the magnitude of the dc input. The platinotron is further characterized by the fact that if the rf drive for a given level of dc input is reduced to too low a value, the device ceases to be an amplifier. This is not a large restriction since pulsed radar applications require a saturated amplifier, and frequency-modulated transmitters can also make use of a saturated amplifier.

To obtain detailed information on the performance of the Amplitron, it was necessary to devise suitable test procedures. Early Amplitron tests on the QK520 were made using a magnetron driver. The results of these tests were not generally satisfactory, mainly because the output spectrum from the signal source was quite poor and so any degradation caused by the Amplitron could not be accurately determined. Thus, it was necessary to await the availability of a driver which could develop a very nearly theoretical spectrum over a 100 megacycle tuning range. The Stabilotron driver, developed during this period, proved satisfactory for this purpose. Figure 3 is a photograph of the test setup used, while Figure 4 represents a block diagram of the setup. The purpose of the iso-

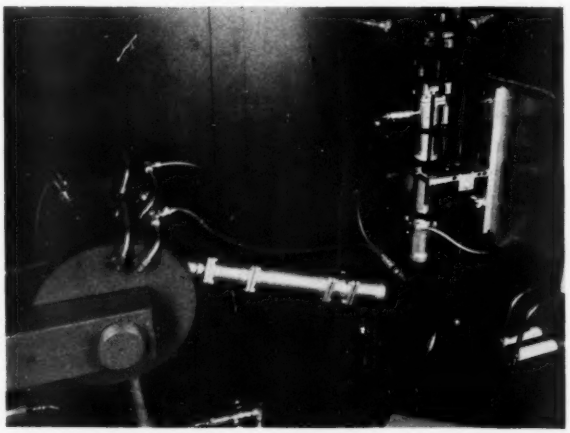


Figure 3. The Stabilotron and Amplitron used together. The Stabilotron and its modulator are to the right of the picture. The Amplitron and its modulator are to the left.

* Raytheon Trademark.

** The output is not strictly independent of the input since the efficiency increases somewhat at higher rf drive, and the rf drive reappears unattenuated at the output and adds to the rf power generated by the platinotron itself.

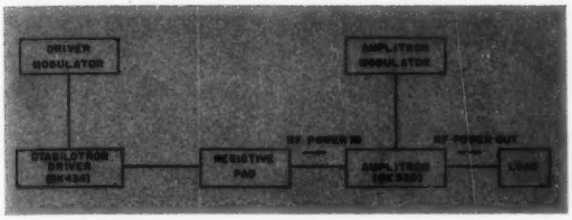


Figure 4. Block diagram for testing the platinotron as an Amplitron.

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In conjunction with the test setup of Figure 4, a photographic technique of comparing input and output spectra, over a wide range of variation of all the parameters, was used, to assure that the quality of reproduction was high and that there was no undesirable degradation in the fine structure of the input spectra. Undesirable characteristics of this kind could easily be overlooked in the routine evaluation of the tube from efficiency, gain, and power handling measurements. With a wide pulse duration of five microseconds, small imperfections in performance show up readily in the spectrum.

The nominal gains obtained from the Amplitron, and the fact that the input rf power reappears as part of the output power, make a definition of efficiency essential. In all results reported in the paper, a conservative definition of efficiency is used:

$$\text{Amplitron Efficiency} = \frac{\text{RF Power Out} - \text{RF Power In}}{\text{DC Power Input}} \qquad (1)$$

The expression for gain is, of course,

$$\text{Power Gain} = \frac{\text{RF Power Out}}{\text{RF Power In}} \qquad (2)$$

The relationship between anode voltage, anode current, magnetic field, power output and efficiency is shown in Figure 5. The magnetic field is usually set at a value which represents a compromise between the greater efficiency which can be obtained at higher values of magnetic field, and the weight of the magnet, which also becomes greater at higher magnetic fields. Once the magnetic field is selected, it determines the relationship between anode voltage and current. In the platinotron, the relationships between magnetic field, anode voltage and current, frequency, and dimension of the interaction area follow closely those for a magnetron.*

If the magnetic field applied to the tube and the magnitude of the rf input are fixed, as is usually the case in a practical application, the relationship between frequency and current level at which the tube is operated is the important and practical consideration. This relationship is shown in Figure 6 in which the quality of reproduction of the input signal is noted at intervals of 25 mcs in frequency, and 5 amps of anode current. Figure 7 presents this same data with contours of constant gain and efficiency replacing the spectral data. It may be noted that the efficiency varies only slightly over the entire frequency band of operation.

Of primary importance in the use of an amplifier is its performance under variable load conditions. Figure 8 indicates that the quality of the output spectrum remains unperturbed regardless of phase position of output mismatch and VSWR up to a value of 2.5. The data in Figure 8 is also of interest in that the power at the match point indicates a gain of 16 db over the rf input power.

The presentation of material on the Amplitron use of the platinotron would not be complete without mentioning the low phase-pushing figure which is an inherent property of this device. Unlike most microwave amplifiers in which the phase of the rf output

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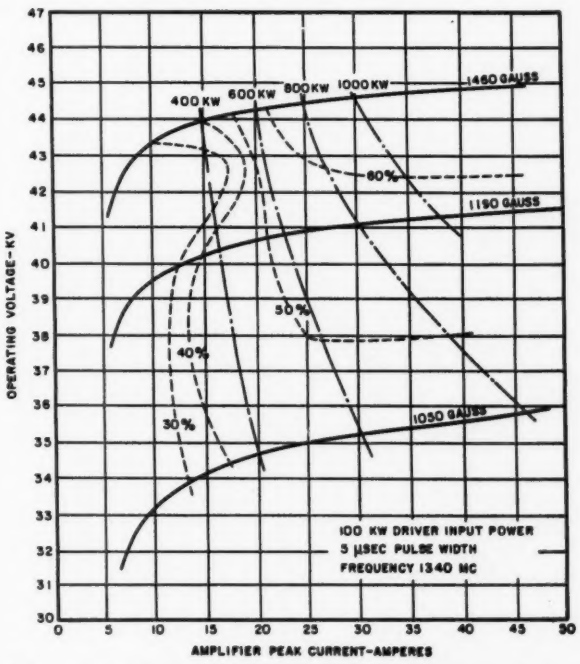
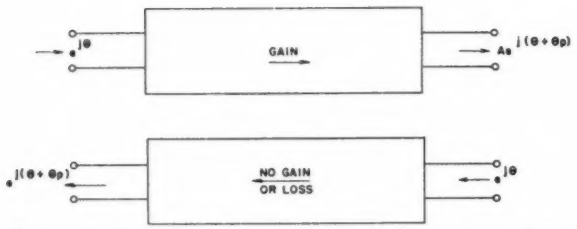


Figure 5. Amplitron matched load performance as a function of anode current, anode potential, and magnetic field.



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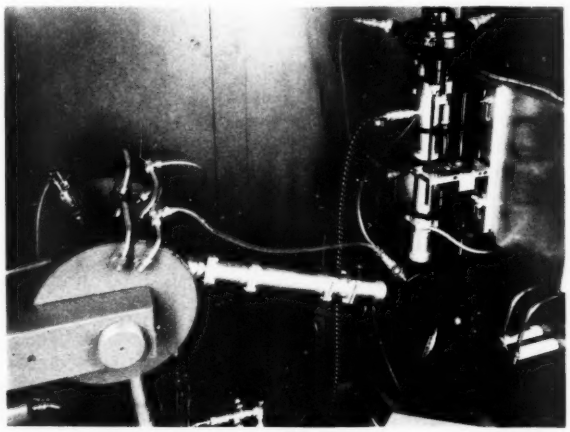

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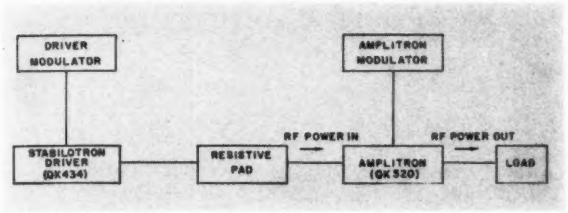

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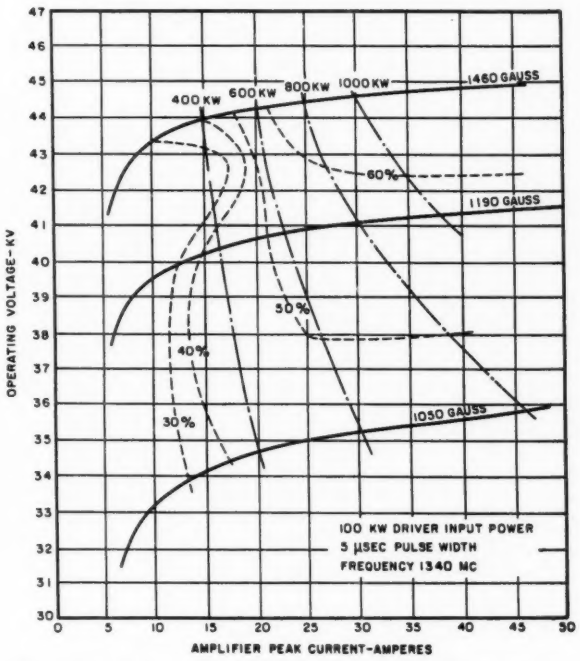

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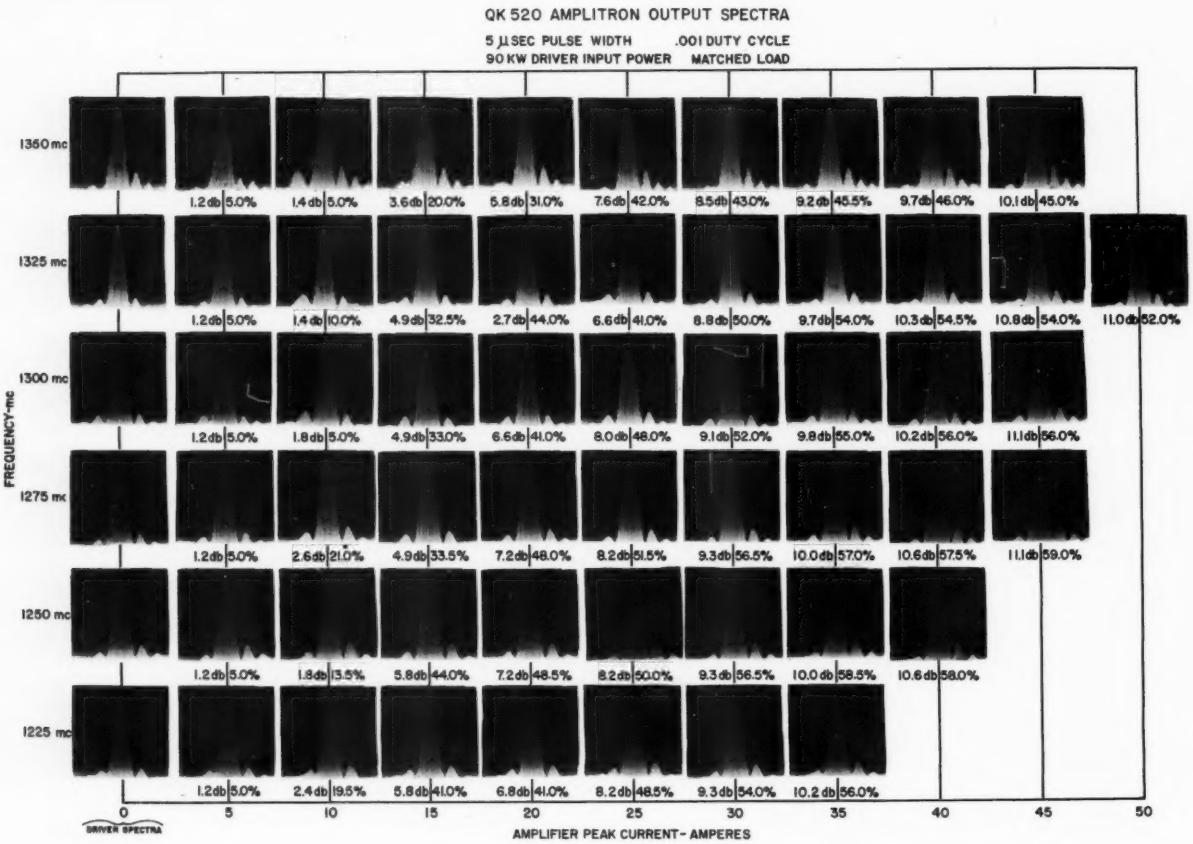


Figure 6. Amplitron matched load performance as a function of anode current and frequency at an rf input level of 90 kilowatts and with the magnetic field held constant. Output spectra photographed at increments of five amperes of anode current and 25 mc/sec of frequency. Output spectra at zero anode current is identical to input spectra.

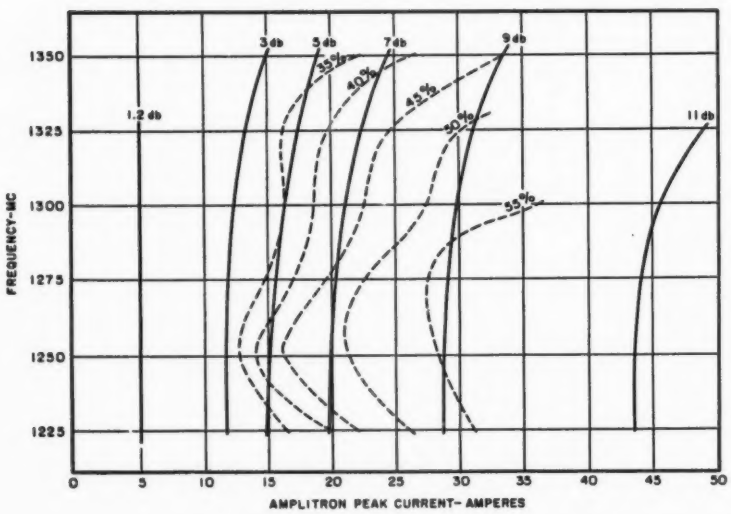


Figure 7. The information in Figure 6 replotted to show contours of constant gain and efficiency.

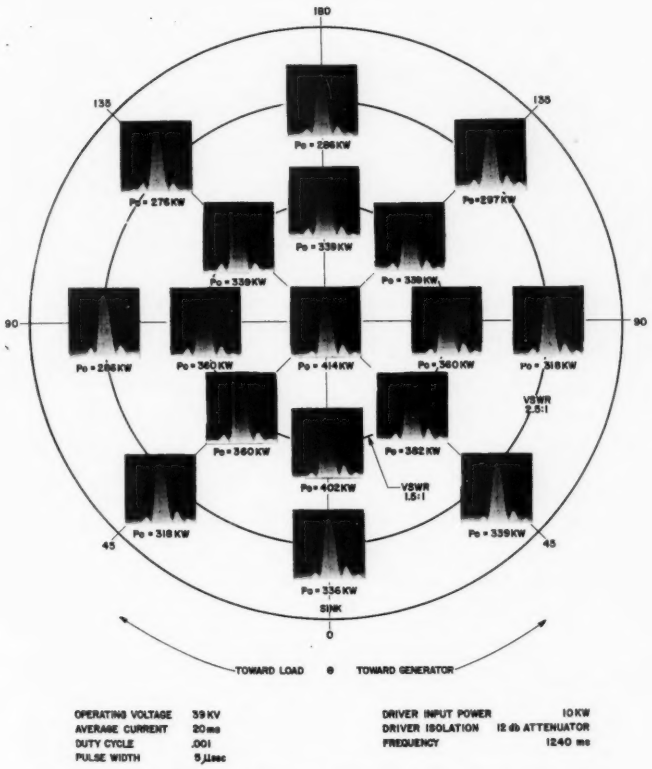


Figure 8. Amplitron performance as a function of load at 1240 mc/sec and with an rf input level of 10 kilowatts.

varies rapidly with a change of operating voltage or current, the phase of the rf output of the Amplitron is relatively insensitive to such changes in the power supply. This makes it possible to dispense with highly regulated power supplies for the final amplifier, where the cost for a regulated power supply would be the greatest.

An important property of the platinotron is its high efficiency. It possesses an average or nominal efficiency of the order of 60%. Carefully measured efficiencies of as high as 75% have been noted under conditions of high rf drive powers and high peak power output. The fact that these high efficiencies have been obtained with little or no attention having been given to designing for high efficiency, and the fact that there are several approaches to increasing the efficiency, give considerable support to the hope that even higher efficiencies may be obtained.

In conclusion, the platinotron has been found to have a number of outstanding performance characteristics which will make it attractive to systems engineers. In spite of diligent search, no undesirable characteristics which would exclude it from general acceptance have been found. A summary of platinotron characteristics, along with the characteristics of competing devices, is presented below.

Characteristic	Power Platinotron	Power Klystron	Power TWT
Efficiency (%)	50 – 75	25 – 50	10 – 40
Peak Power Output* (megawatts)	2 – 7	2 – 10	0.5 – 1
Av. Power Output (kilowatts)	8 – 10	2 – 10	0.5 – 1
Bandwidth** (%)	10.0	0.2 – 1.0	10 – 30
Gain (decibels)	10 – 16	25 – 40	10 – 25
Phase Pushing	0.2°/1 % change in power supply voltage	3 – 6°/1 % change in power supply voltage	3 – 6°/1 % change in power supply voltage
Operating Potential (KV)	30 – 70	90 – 200	70 – 100
Auxiliary Gear	Permanent magnet 40 – 100 lbs	Electromagnets, power supplies, and lead shielding for X-rays	Electromagnets, power supplies, and lead shielding for X-rays
Duplexing at Input	Yes	No	Possible by redesign
Conversion to Highly Stabilized Oscillator	Yes	No	Possible by redesign

* Sealed off tubes

** Bandwidth to 1 db points

Comparison of the performance characteristics of the power platinotron, power klystron, and power traveling wave tube.

Casting resin being poured over transistor, preparatory to metallographic sectioning. The hardened plastic provides a convenient handle for subsequent polishing operations.

Final polishing with 0.25 micron diamond powder. The lap is covered with a special cloth which retains the diamond powder as the lap rotates.

Metallography Applied to Semiconductors

K. BERBERIAN
Receiving and Cathode Ray Tube Operations

METALLOGRAPHY, the microscopic study of the structure of metals and alloys, is a powerful tool in the ever-broadening field of Metal Physics. Its importance has been particularly emphasized by the advent of the semiconductor, the study of which has created a demand for a variety of new techniques.

Because of the fragile nature of transistors and other semiconductor devices, the basic techniques of metallography have had to be refined considerably beyond those applicable to materials like steel. Conventional metallographic specimens would be mounted or potted in materials like Bakelite and Lucite for polishing. For proper setting, however, both these materials require temperature (approximately 150° C) and pressure (approximately 3000 lbs. per square inch). This temperature is enough to melt some semiconductor alloys and the pressure is enough to crush the germanium or silicon chips used. Therefore, transistors are usually potted in a polyester casting resin. Such a material cures either at room temperature or slightly above, and no pressure is required.

Other basic operations present equally difficult problems. Grinding and polishing are a challenge because there is often a very soft material such as indium adjacent to a very hard material such as germanium. The use of very fine diamond powder or paste for polishing has greatly simplified this problem. Etching techniques have also been refined. To reveal the junctions in germanium and silicon, it is necessary to use a selective etch which differentiates between p- and n-type materials. Various combinations of hydrofluoric, nitric and acetic acids have been used successfully for this purpose.

All this effort has been expended on the development of sectioning techniques because the micro-

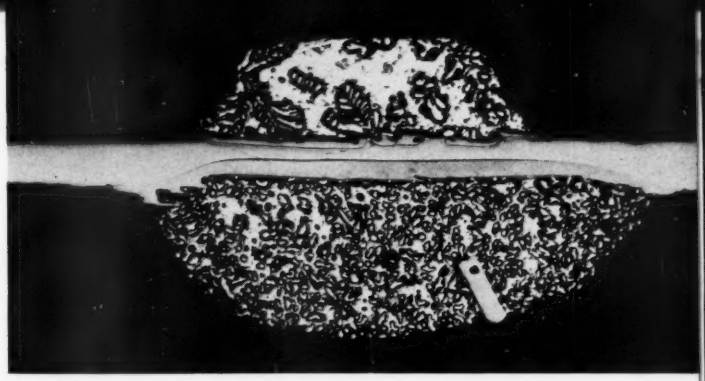
Examining etched metallographic section on the metallograph. Silicon audio transistor displayed has a basewidth of 0.00017 inches.

structure in a photomicrograph can readily be correlated with many of the electrical parameters measured on finished transistors. To obtain high current gain and good frequency response, for example, the basewidth should be narrow and the junctions flat and parallel. A very narrow basewidth, however, may result in shorting effects between the collector and emitter when even low voltages are applied. Current gain of a transistor is also a function of the relative areas and general geometric relationship of collector and emitter, easily measurable on a photomicrograph. High current gain at high current densities can only be obtained if the collector and emitter regrown regions exceed a certain minimum thickness.

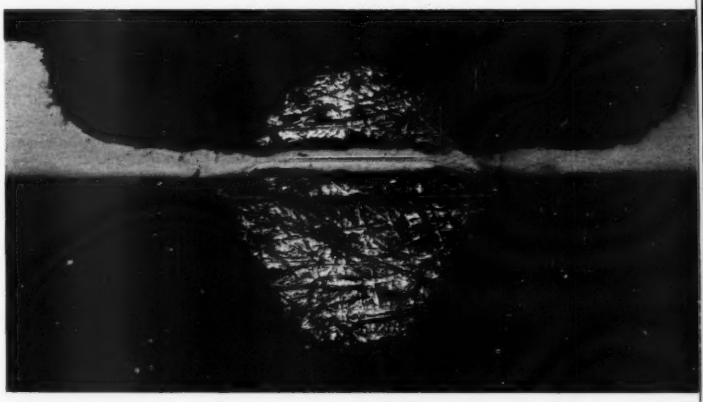
Voids and discontinuities in the regrown regions make the electrical parameters of a transistor erratic and indicate possible contamination of the materials. Another detail that can be observed is cracking under the collector and emitter dots, occurring sometimes when the expansion and contraction characteristics of the dot alloys do not match those of the germanium or silicon base material. This usually results in the transistor being electrically open or at best a low-gain unit.

That etch pits show up clearly is also of considerable interest since under certain conditions these coincide with the presence of dislocations which measure crystal perfection. Dislocations have a marked effect on the lifetime of the crystal and also influence other factors such as the wetting of germanium and silicon by the dot alloys used for collectors and emitters. Indeed, it may well turn out that too perfect a crystal may not be satisfactory for transistor fabrication.

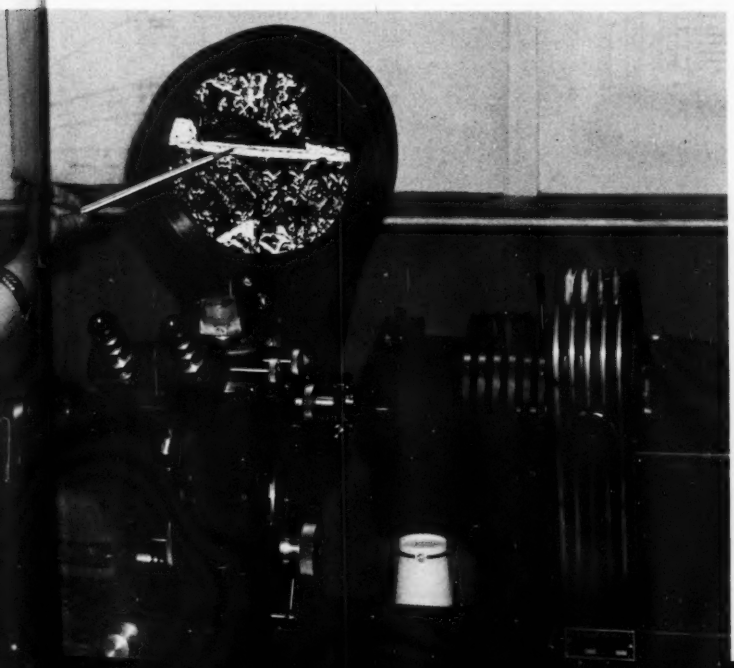
The way in which metallography can be used for the prediction of semiconductor device characteristics is illustrated by the photographs on these pages.



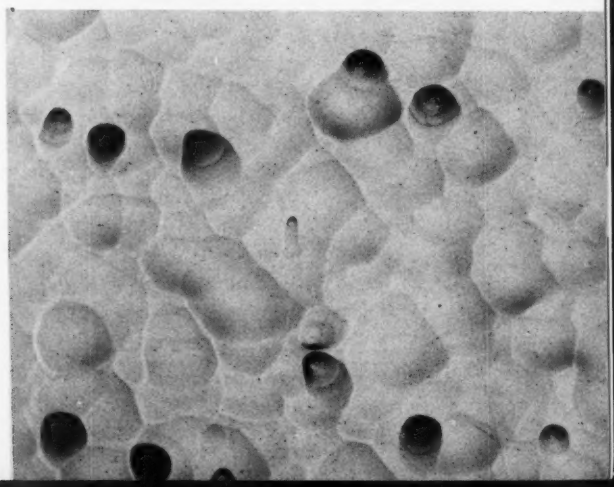
Photomicrograph of silicon audio transistor. The collector and emitter are made with an aluminum-tin alloy. Note the smooth collector junction with a fairly wide regrown region. The emitter junction shows discontinuities which could cause the unit to be an emitter to base short. The silicon chip is 0.005″ thick.



Photomicrograph of a germanium high frequency transistor made by alloy fusion into a slotted chip. Both the emitter and collector junctions are flat and parallel. The basewidth of this transistor is 0.00025 inches. The cut-off frequency for this transistor is about 30 megacycles.

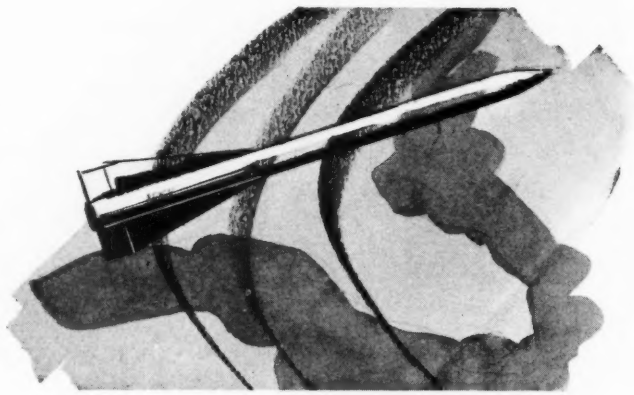


Etch pits in single crystal germanium. Each pit represents a dislocation. The crystal shown here has a dislocation density of 3.2×10^3 dislocations/cm². The shape of the pits is characteristic of the (111) plane of orientation.



Reliability—A Must

W. E. LOWERY
Wayland Laboratory



A SUITABLE introduction to the subject of reliability ought to include both a definition of our rather broad topic and an indication of its relative importance. Several definitions have been proposed, but the one adopted by the Radio Electronics Television Manufacturers Association (RETMA), and in most common use, is:

> "Reliability is the *probability* of a device *performing its purpose adequately* for the *period of time* intended under the *operating conditions* encountered."

Note the four important factors of reliability: probability, adequate performance, time, and operating conditions, and keep in mind that all four are essential in any discussion, report, or evaluation of reliability.

The importance of reliability may be attested to by military people who are often plagued with short-lived electronic equipment which, in many cases, is difficult or practically impossible to maintain with reasonable amounts of manpower and facilities. It can be seen that this condition may result in failures which can cause disastrous losses in men and materials. Attempts to compensate completely for such deficiencies, in the field, would result in enormously expensive maintenance and spare parts support efforts. In fact, some writers have indicated that, if nothing were done to reverse the "high complexity-low reliability" trend, in a very few years the number of technicians required for military maintenance alone would be greater than the total number of men now in all of the Armed Forces.

In order to impart a feeling for the numbers involved, it is helpful to consider a specific situation. A certain airborne system, to be installed in a manned aircraft, contains about 4000 parts, failure of any one of which constitutes failure of the system. The reliability objective is that there be 0.98 probability of completion of a ten hour mission without failure. Assuming failures to be distributed in time in a random manner, the mean time to failure would be 500 hours. This figure is derived from the equation $P_s = e^{-t/m}$ where "P_s" is the probability of success during the time "t," and "m" is the mean time to failure.

Now, according to some authorities, this would mean that, on the average, each of the 4000 parts must have a mean time to failure of 500 x 4000 or 2,000,000 hours. Translated into the common expression for failure rate, there would be 0.05% failures per 1000 hours per part. Since the best generally acceptable parts when used within their generally acceptable ratings produce failure rates at least twice as high as this, it will be seen that even present projects require more than casual effort on reliability.

Let us now think about means for determining or predicting reliability. Of course our customers are interested in knowing what the ultimate operational performance of the equipment in its true environment will be. Unfortunately this will not be known until many equipments have been made, used, and reported on. This condition will not be reached for many months after completion of production, if ever. Consequently, something which happens sooner and which can be made subject to confirmation by representatives of both producer and customer must be agreed on. In this category are extensive life tests, conducted on complete systems under definite controlled environmental conditions. It is true that such experiments will not duplicate actual installation, operation and maintenance conditions, and will enable a prediction only of "inherent reliability" at best. However, they will serve as reference levels, so that the effects of changes in design, improvement of parts, and operation of quality control may be known.

In order to see how such a reliability test might work, let us take a hypothetical case, using the same airborne system mentioned above. If it were arbitrarily decided that sufficient allowance for the difference between test and actual conditions could be made by requiring the equipment as manufactured to be failure-free for eleven hours instead of ten hours, the requirement for the test would be a demonstration of 550 hours mean time to failure ($0.98 = e^{-11/m}$, from which m = 550). Now if it were supposed that the equipment met the requirement exactly, one might think that proof would be obtained if one failure was encountered in operating one equipment for 550 hours,

or in operating eleven equipments for 50 hours each. However, according to statisticians, this would not be true. Because failures are randomly distributed in time, estimates of mean time to failure from any finite set of data have some degree of uncertainty associated with them. This is where confidence limits come in. The width of the confidence interval depends not only on the degree of assurance that is desired, but also on the number of observed failures. If, in our hypothetical case, ten equipments were operated for 550 hours each (a total of 5500 equipment-hours) and ten failures were observed, then although the calculated mean time to failure would be 550 hours, we would know with 90% confidence only that the true mean time to failure lies between 265 and 835 hours. $(550 \pm \frac{1.64 \times 550}{\sqrt{10}})$ *. If greater precision was required, it could be obtained by operating the equipments for a longer time, say twice as long. If 20 failures were then observed, the calculated mean time to failure would still be 550 hours, but now there would be 90% confidence that the true mean time to failure was between 348 and 752 hours. See Figure 1.

The foregoing serves to illustrate that when reliability requirements are specified, there must be a clear understanding all around as to how the degree of reliability will be demonstrated, and to what degree of assurance the answer is required.

At this point, the general engineering reader is apt to feel that the case is hopeless, because he sees no way to progress in clear orderly fashion from initial design effort to finished equipment which meets requirements. No one will claim that the way is easy. A lot of work has gone into determination of methods for predicting reliability and for designing to specific reliability requirements.

One large concern has developed techniques for evaluating components for their intended use by formulating a most probable mechanism of failure for component families, fitting into this framework the bits of information available from life tests and field failure reports, and estimating individual failure rates. They then compute overall failure rate for the equipment from the combined failure rates of the component parts. They claim to have achieved good correlation with field failure results. In the case of a complex communication system, a mean life of 125 hours was predicted, and a mean life of 116 hours was observed during carefully controlled field evaluation of 100 complete equipments.

A large West Coast company has concentrated on in-plant testing of complete equipments for significant lengths of time and on quick action in determining modes and causes of failures. During a continuous production run of a certain airborne equipment, they obtained an improvement of 150% in equipment mean life during a six month period. They also claim good correlation of failure rate with results of field operation of about 40 equipments.

Vitro Laboratories, operating under a BuShips contract, has investigated and reported on techniques for reliability measurement and prediction. Following the analysis of several thousand failure reports on fifteen types of shipborne equipment, they arrived at a method of determining prediction guide lines for parts used in such equipment. For each class or family of components, several "application severity levels" were determined, and for each level, failure rates were established on the basis of field failure data. They concluded that (at least for the type of equipment observed) reliability prediction is feasible on the basis of design factors which are evident in the drawing board stage of an equipment's development.

CURVES SHOW INCREASE IN PRECISION OF MEASUREMENT WITH INCREASE IN NUMBER OF OBSERVED FAILURES. THEY ARE GIVEN FOR CONFIDENCE LEVELS OF .68, .90, AND .95

ALL THREE SETS OF CURVES RELATE TO TESTS WHERE $\frac{\text{EQUIPMENT TEST HOURS}}{\text{NUMBER OF FAILURES}} = 550$

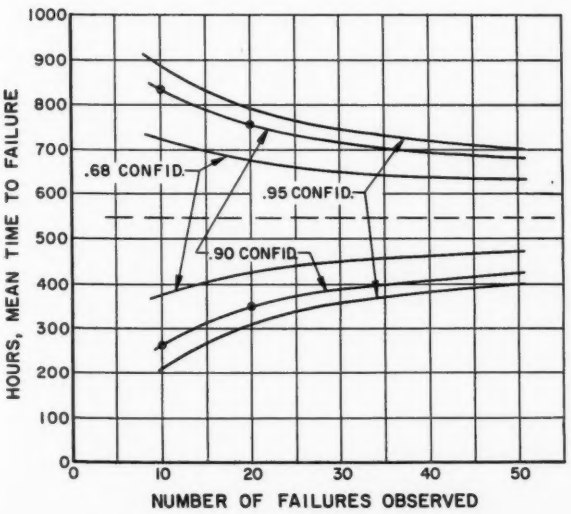


Figure 1

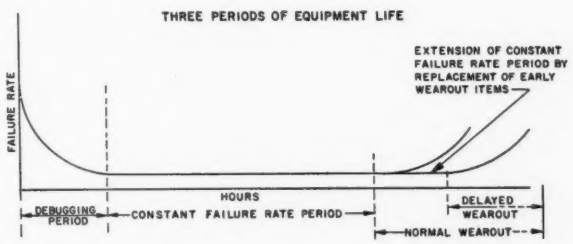


Figure 2

* See Vitro Technical Report No. 80, 10 October 1955, pp. 6–9.

One of Raytheon's customers is making extensive analyses of failure data accumulated during in-plant and field operation of a complex electronic system. It is perhaps too early to be certain, but it is beginning to appear that they will arrive at prediction guide lines for component parts used in some types of airborne equipment.

In all of the preceding discussions, the failure rates mentioned were for thoroughly "debugged" equipment. It was assumed that all parts which were marginal from an initial quality standpoint had been eliminated during normal operational and run-in tests. If this were not the case, mean time to failure figures obtained in the factory or during the early hours of operation in the field would be misleading, because of the inclusion of debugging time failures which should have been detected by the equipment manufacturer. This brings us to the old statement that *reliability can not be tested into a product.* It is certainly true, but it should also be said that unless there has been enough testing to cause removal of initially poor or marginal parts, the true reliability of the equipment may never be known.

As noted in Figure 2, there is a time when the normal reliability portion of equipment life is over. Certain parts, by their nature, begin to wear out. When this occurs, failure rate is no longer substantially constant, or put in another way, failures are no longer merely random ones. Sometimes, when there are only a few inherently short life parts, and these parts are known, planned replacement of them will effectively extend the constant failure rate life of the equipment. This also is shown in the figure.

From what has been said up to this point, it may appear to some people that reliability is the sole responsibility of the design engineer. While it is true that it adds one more item to the already long list of things to be considered in design, it just as surely adds the same item to everybody else's list. To demonstrate this, a tabulation of some of the factors which influence the ultimate reliability of our equipment is presented below:

Military needs and characteristics
System analysis
Specifications
Standards
Initial design and breadboarding
Selection of materials and parts
Engineering model design, drafting, construction, evaluation
Service Test
Design for production
Prototype construction, evaluation
Design, manufacture and quality control of parts by vendors
Procurement of materials and parts
Inspection and testing of subassemblies
Inspection and testing of complete equipment
Packing
Shipping
Storage
Installation
Maintenance
Operational practices
Failure reporting

The all-inclusiveness of this list makes it obvious that none of us can escape responsibility for the final reliability of the equipment that we produce.

OPERATING-TIME INDICATORS

W. T. ERIKSEN
Research Division

THE rapid multiplication of electronic equipment in aircraft has raised the problem of component reliability to major importance. It has been shown that the majority of down time for modern military aircraft is due to breakdown of electronic equipment rather than mechanical failures. The solution to this problem lies in obtaining sufficient reliability data on components so that lifetime can be predicted and components changed before failure. The modular system of packaging lends itself to such a reliability study, since components are packaged in large enough blocks to permit incorporation of a small operating-time indicator in each module.

To be practical, an operating-time indicator must be small, light, economical, and flexible enough in power requirements and total operating time to be used in different types of equipment. Extreme accuracy is not as important as the above mentioned factors, since the statistical spread in lifetime of a component will be quite large. Mechanical timers are impractical for size and economy reasons, and their use must be governed by the voltage and frequency of available sources of power.

A practical means of timing is to make use of Faraday's law of electrolysis. Stated very simply, this says that the amount of a metal plated onto an electrode is directly proportional to the quantity of electricity passed through the cell. At constant current, the quantity of electricity is a linear function of time. If one can measure the amount of metal plated out at constant current, the time of plating can be calculated. The primary disadvantages of this system are the difficulties encountered in making a time reading (which usually involves a subsidiary measurement of some complexity) and in obtaining routine measurements with relatively untrained personnel.

An electrochemical time indicator has been developed which minimizes the difficulty of the subsidiary measurement and contains, to a large degree, the desired features of smallness, lightness, economy and flexibility. This device is, at present, being packaged in a subminiature tube envelope, as shown in Figure 1.

The operating time indicator consists of a small glass cell containing an anode and cathode which are made of an electrochemically inert material. Operation depends upon the passage of a constant direct current through the cell, thereby "plating out" the metal ions onto the cathode. Under these conditions, the concentration of metal ions in solution is inversely proportional to the time the current has been on. The measurement of concentration is made by using a colored metal ion (in this case, copper) and relating

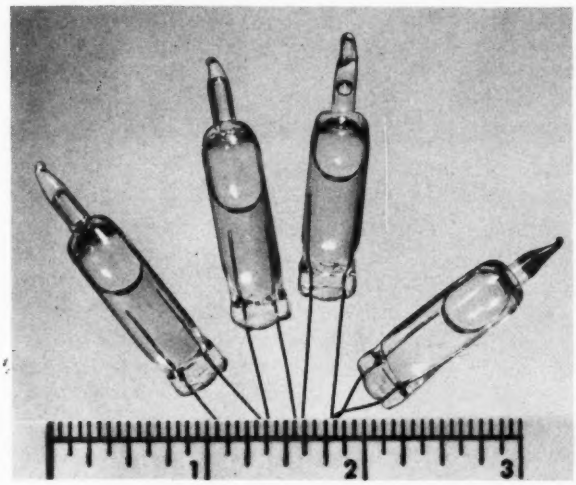


Figure 1. Sample Operating Time Indicators

the absorption of light by the solution to the concentration of metal. Since white light cannot normally be used, a filter is necessary to isolate a relatively narrow region of the spectrum.

The absorption of light by a solution is described by Beer's Law:

$$\frac{I}{I_0} = e^{-KlC}$$

where I is the intensity of light through the solution (measured with a photocell).

I_0 is the intensity of the original light beam.

l is the length of the optical path.

C is the concentration of the metal ion in solution.

K is a proportionality constant characteristic of the particular system.

Taking the log of both sides of the equation and considering l and K constant, the equation becomes

$$\log \frac{I}{I_0} = -K'C$$

Thus, simply by comparing the intensity of the light passing through a cell with that of the unobstructed light beam, the concentration of metal ion is known. K′, the proportionality constant, can be determined by making up a series of known concentrations and measuring log I/I_0.

In an electrolytic cell, there are always two reactions taking place, the one of primary interest being at the cathode and the other at the anode. This latter reaction must not be permitted to interfere with the cathode reaction or change the color of the solution in the cell. The main difficulty to be overcome is the evolution of gas at the anode. Since the cells are sealed and have very little free volume, gas generation over extended periods could build up rather large pressures, with catastrophic results. An additive is therefore included to prevent gas evolution. This compound, which will react easily at the anode, is colorless in both reacted and unreacted forms, and does not interfere with the cathode reaction.

The next step in a practical system of obtaining operating times is to simplify as much as possible the subsidiary measurement to extract the time reading. In this case the time reading comprises a measurement of light absorption and a correlation to metal ion concentration and thence to time. These correlations can be reduced to one proportionality constant between light absorption and time by specifying the starting concentration of metal and the current which should be passed through the cell. The instrument used for this is shown in Figure 2. Other less complex methods are presently under investigation.

Operation of the indicator in the field is obtained by wiring the small glass cell to the plate supply of the electronic equipment in series with a resistor which is specified for the voltage rating of the power supply. At such time as the equipment fails and is brought to a depot for repair, the time cell is removed, dropped into the colorimeter and the time reading made by a simple adjustment of a variable resistor.

It is felt that this system will be of value in obtaining reliability data on electronic systems and components, and will be simple and economical enough to be of very general use.

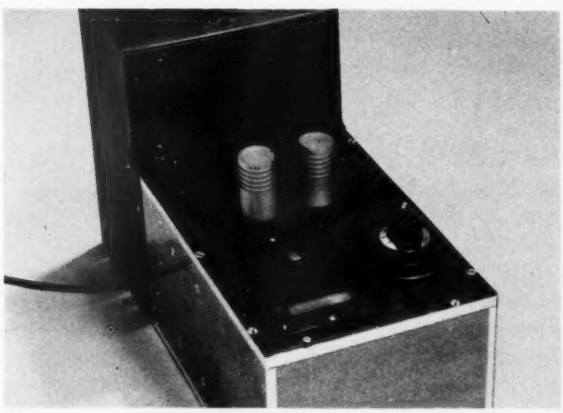


Figure 2. Colorimeter Used for Time Readings

PRODUCT ENGINEERING

A. D. WHITE
Microwave and Power Tube Operations

THE term "Product Engineer," as used at the Power Tube Division, applies to that segment of engineering personnel closely affiliated with the various manufacturing phases of the division's product. It matters little whether the product engineer is involved specifically with klystrons, transmitting tubes and rectifiers, or magnetrons insofar as his basic responsiblities are concerned. Other divisions may have different designations for the same type of engineering, but essentially similar functions are performed throughout the company. As an example, consider the work of a magnetron product engineer.

One of the major products for which Raytheon is known is the microwave magnetron, and magnetron product engineering encompasses a particularly challenging variety of engineering activities and responsibilities. Most magnetron types that have been released from design have not yet been made in sufficient quantity to have been thoroughly debugged. Time and/or money is rarely adequate to permit the building of more than a very few prototypes — usually hand-assembled and processed by skilled technicians. It is the product engineer's first responsibility to adapt these designs to economical manufacturing operations using existing production facilities and personnel where possible, and then to direct the development of new or altered facilities, methods, and processes where necessary. In this effort he must coordinate closely the work of other service groups, such as the methods and industrial engineering groups and the quality control section, to provide the production department with specifications which clearly state exactly how the type is to be made. It is frequently necessary to effect some redesign of the type during this period, and here he must draw heavily on his own technical training and experience, especially if during the original design it was not possible or believed necessary to investigate particular features now under question. During all this, he must not allow his technological enthusiasm to overbalance his sense of good economics, nor must the original performance requirements of the type be violated.

As the type goes into production, a high degree of cooperation is required between product engineers and production supervision. A product engineer must be available for personnel instruction concerning the operation of new or unfamiliar equipment and the procedures to be followed for new processes. He must be alert for any further weaknesses in tube design, manufacturing equipment, or processes, and these must be corrected with speed and accuracy as the inertia of a production line and its associated procurement activities is tremendous. Inspection points must be set up at economically strategic locations. Here, too, an occasional redesign may be required to aid inspection. Usually, a change in dimensioning points will suffice, but frequently the entire redimensioning of fairly complicated assemblies may be required.

As production starts to flow, each instance of excessive scrap must be investigated, its cause determined and eliminated. Again, speed is important and the value of forethought and planning becomes increasingly apparent. While further experience is being gained with the type, constant watch must be maintained to observe points where less expensive or non-strategic materials may be substituted for those in the original design. In cooperation with production supervision, tube design and manufacturing facilities are further modified to effect consolidation of operations for cost reduction. The product engineer must be constantly aware of the electrical and mechanical performance of his types in meeting customer specifications including life test; and, through the applications engineering group, he must be cognizant of field performance. Deviations from optimum performance require immediate analysis and correction. The causes of these deviations, like instances of part, assembly, or tube scrap, lie in a very broad area from the relatively easily corrected "operator goof" to the subtility of an undesired RF resonance that is present only under a particular coincidence of several dimensional tolerance values.

Under the economic impact of higher labor and material costs, a steady effort must be maintained to hold the cost of the finished product to a level which will maintain the magnetron's, and Raytheon's competitive position. A continual program of redesign to allow use of more economical material, methods, and processes is carried on as long as the tubes are being manufactured. Machined metal and glass parts have been replaced with molded plastics where suitably strong and heat resistant materials have been made available. Where performance requirements permit, both material and structural changes have been made to take advantage of modern arc-welding techniques. A standard piece of heavy duty spot-welding equipment is adapted for use as a brazing machine, and through the use of a self-fluxing solder, a large increase in the productivity of the brazing labor and a more uniform product is obtained. Complex machined assemblies are broken down into elements which can be punched in volume from dies or hobs or which require only relatively simple machining, and the assemblies are then made up from these parts by sequential brazing in conveyor or RF furnaces. Through such efforts as these, constant pressure is maintained to hold the line on product cost and to provide the margin of profit without which there can be no further development or expansion.

The microwave segment of the electronics industry, in common with other highly technological industries such as aeronautics, is faced with rapid obsolescence of its products. No sooner has a magnetron been placed in production than it is asked to meet new requirements. Thus, additional design and process modifications must be made while the tube is being produced. This means that the product engineer must initiate and evaluate his own modifications while at the same time keeping a sharp eye on the performance of the existing construction. Close contact must be maintained with the scheduling and procurement groups so as to achieve the best economic balance of matching parts and assembly inventories as the new model replaces its predecessor. All this, of course, must be done with an absolute minimum of disturbance to the flow of products "out the door" since that, and that alone, pays the freight.

High Speed Vibration Testing

In short, product engineering requires a diversified background in the Electrical, Mechanical, and Chemical Engineering fields. In addition to technical ability, patience and tact are mandatory, as well as a nature sufficiently agile to move quickly from problem to problem under pressure. The work is interesting, challenging, and noted for its complete lack of boredom.

Publications & Papers

These papers have been approved by Raytheon's Technical Publications Panel:

Alfred Blattel	"Fast Operation Time in Subminiature Tubes"
David L. Bobroff	"New Coordinate Systems and Concepts in Electron Beam Analysis"
W. C. Brown	"Ceramic-Metal Seal Outgassing Study, QK608 Quarterly Scientific Report No. 3, October 1, 1956–December 31, 1956"
W. C. Brown	"Description and Operating Characteristics of the Platinotron — A New Microwave Tube Device"
W. C. Brown	"The Platinotron, Amplitron, Stabilotron — New Microwave Tube Devices"
David A. Copson	"Experimental Microwave Energy Procedures in Food Preservation"
David A. Copson	"Special Utensil Construction and Procedure for Microwave Angel Food Cake Baking"
L. J. Cronin	"Reactions Between Alumina and Refractory Materials"
K. V. Curtis	"Improvements in Radar Data Presentation"
Dilip K. Das	"Some Reactions Involving W, C, Th and ThO_2"
Erich Schulz-DuBois	"Development of Ferrites for Low-Frequency High-Power Isolators"
Ray C. Ellis, Jr.	"Etching of Single Crystal Germanium Spheres"
W. T. Eriksen	"Field Modulation of Liquid Induced Excess Surface Currents on Germanium Diodes"
W. T. Eriksen	"Conduction Mechanisms on Semiconductor Surfaces"
Y. Golahny	"Silicon Diodes as Logarithmic Elements"
Bernard P. Goldsmith	"Estimation of the Standard Deviation by Order Statistics, The Range, The Average Range, and Some Quasi Ranges"
Otto Guentert	"Effects of Layer Faults in Diamond Structures on X-Ray Diffraction Patterns"
Hermann A. Haus	"Theory of Large C Magnetron Amplifiers"
Donald A. Hedlung and Leonard C. Edwards	"An Experimental Investigation of Ionospheric Forward Scattering at HF"
P. Kaufmann	"High Frequency Transistors"
P. Kaufmann	"Flow Graph Analysis of Transistor Feedback Networks"
P. Kaufmann	"Relations Between the Current Amplification Factors and the Diode Saturation Currents"
W. W. Keith and F. E. Sears III	"Field Test Equipment for Airborne Radar"
Dr. Rockwell Kent	"Trace Analysis of Refractory Materials"
L. F. Kilham, Jr., J. F. Ahearn, and R. Ursch	"Cooling of Electronic Equipment by Means of Heavy Inert Vapors"
A. S. Lange	"Automatic Controls in Weapons Systems"
M. Levy	"Some Problems Associated with the Development of a High Tolerance Precision Laminate for High Performance Aircraft Use"
Dr. Melvin Mark and Mark Stephenson	"The Thermal Conductivity of Core Materials for Sandwich Construction"
Ralph L. Mondano	"The Future of Plastics" — a general presentation on plastics and their properties
Ralph L. Mondano	"Proposed Method and Test Results of Dielectric Strength at Elevated Temperatures and Some Interesting Applications of Plastics in the Electronics Industry"
W. L. Pritchard	"Statistics of Standing Waving Ratio"
Lawrence G. Rubin	"Ferrites — 1957"
Charles G. Smith	"Motion of an Arc in a Magnetic Field"
H. Statz, R. A. Pucel and C. Lanza	"Devices with Two Contacts in Space-Charge Regions"
T. A. Weil and B. Erdman	"A High Performance Transistor-Regulated Power Supply"
Thomas A. Weil	"Transmitter Stability Requirements for Coherent MTI Radar Systems"
Thomas A. Weil	"Biased Chokes for Improved Swinging Choke Action"
G. J. Wheeler and J. Reed	"A Broadband Fixed Coaxial Power Divider"
G. J. Wheeler	"Broadband Waveguide-to-Coax Transitions"
W. A. Whitcraft, Jr.	"Aircraft Reflections in VHF Communications Systems"
Donald L Winsor	"The Electronics of Domestic Microwave Ovens"
S. P. Wolsky	"Vacuum Microbalance Experiments with Germanium and Silicon"
Ross Wood and Thomas J. White	"Operation of Tube Type CK6832 as a DC Differential Amplifier"

NEW—Raytheon Amplitron

Now—peak power 800 kw, bandwidths of 10% with efficiencies of 50-70% over entire band

QK620 Amplitron
Typical Operation (Pulsed)

Anode Voltage	40 kV
Anode Current	35 amps
Peak Power Output	800 kw
Average Power Output	1200 watts
Efficiency	55%
Operating Band (±1 db)	1225-1350 Mc
Peak Power Input	80 kw
Phase Stability with Anode Current	1°/amp

The Amplitron is a new type of tube capable of power amplification at microwave frequencies. Amplification is obtained over a broad range of frequencies without need of mechanical or electrical adjustments. The Amplitron is a derivative of the magnetron and retains many of its advantages—high operating efficiency, simple construction, small size, light weight, low operating voltage.

The Amplitron uses crossed electric and magnetic fields, a reentrant beam produced by a magnetron-type cathode, and a non-reentrant broadband circuit matched at either end to external circuits.

Variations in anode current or voltage have little effect upon the total phase shift. This results in very low phase pushing and excellent reproduction of the input spectrum even under pulse conditions with slow rise time and ripple. Because of low insertion loss, duplexing may be accomplished at the input rather than the output of the final rf amplifier.

A limited quantity of preliminary literature is now available. To be sure of your copy, write now. *Amplitrons in other frequency bands are currently in development. Inquiries are invited.*

RAYTHEON MANUFACTURING COMPANY

Microwave and Power Tube Operations, Section PT-00
Waltham 54, Massachusetts

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